EDEXCEL Advanced Level

Edexcel IAL Biology Unit 4

Summary©

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HS

TOPIC 5: ON THE WILD SIDE

Photosynthesis

Green plants use the energy from sunlight to produce sugars from the inorganic raw materials, carbon dioxide and water, by a process called photosynthesis. The waste product is oxygen.

carbon dioxide + water + light → organic compounds + oxygen

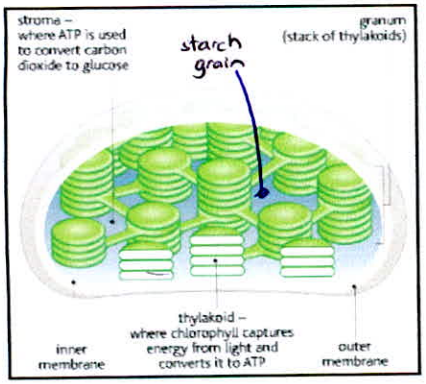
$$6CO_2 + 6H_2O + light \xrightarrow{chlorophyll} C_6H_{12}O_6 + 6O_2$$

This mode of nutrition is autotrophic.

Autotrophic nutrition: The synthesis of larger organic molecules from simpler inorganic compounds.

* Photosynthesis occurs in plant cells containing chloroplasts.

The structure and role of chloroplasts


stroma – where ATP is used to convert carbon dioxide to glucose
starch grain
granum (stack of thylakoids)
thylakoid – where chlorophyll captures energy from light and converts it to ATP
inner membrane
outer membrane

The chloroplast is one of the larger organelles found in plant cells. It turns out that photosynthesis consists of a complex set of reactions, which take place in chloroplasts. The chloroplast is contained by a double membrane with the inner membrane infolded to form branching membranes called thylakoids within the organelle. Some of the thylakoids are arranged in circular piles called grana. Here the photosynthetic pigment chlorophyll is held. The matrix is called stroma.

Grana: Circular piles of membranes (thylakoids)

Thylakoid: Infolds of inner membranes of chloroplasts that carry photosynthetic pigments.

Starch grain: Stores the product of photosynthesis.

The Structure of chlorophyll

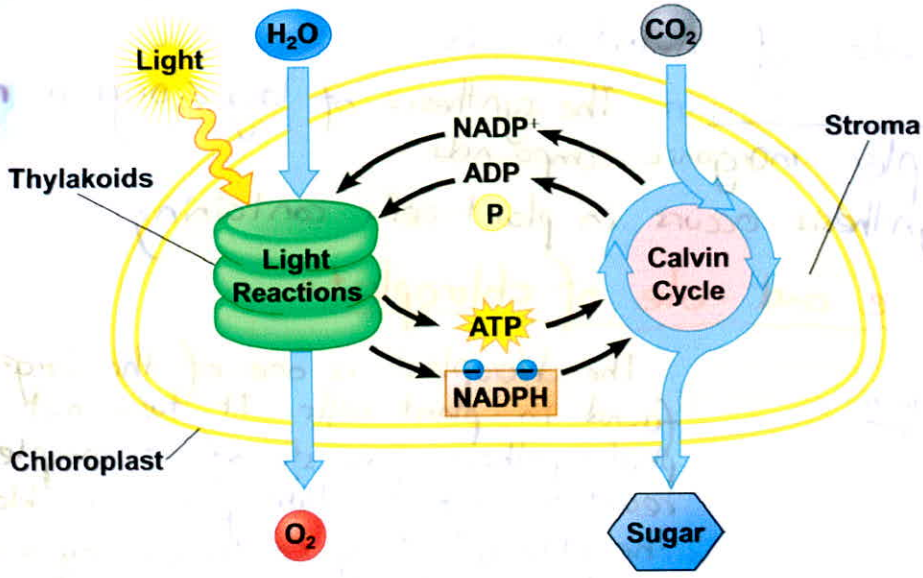
→The chlorophyll molecule has two parts. The head of a molecule is a hydrophilic ring structure with a magnesium atom at its centre. Attached to this is a long hydrophobic hydrocarbon tail. This arrangement means that chlorophyll molecules are attached to the membranes of the chloroplast by their long tails whilst the heads lie flat on the membrane surface to absorb the maximum amount of light.

Photosynthesis: the process

* The overall reaction of photosynthesis requires energy from light to split apart the strong bonds in water molecules, storing the hydrogen in a fuel (glucose) by combining it with carbon dioxide and releasing oxygen into the atmosphere.

The splitting of water by light is called photolysis. The energy for this step is first trapped by the pigment chlorophyll.

The overall process is achieved in two linked stages called the light-dependent reactions and the light-independent reactions. The process is summarised in the diagram below:



The biochemistry of photosynthesis

1-) The light-dependent reactions

In the light-dependent stage, light energy is trapped by the photosynthetic pigment, chlorophyll. Chlorophyll molecules are grouped together in structures called photosystems held in the thylakoid membranes of the grana. Several hundred chlorophyll molecules plus accessory pigments are arranged in each photosystem. All these pigment molecules harvest light energy, and they funnel the energy to a single chlorophyll molecule in the photosystem, known as the reaction centre. The different pigments around the reaction centres absorb light energy for slightly different wavelengths.

- Photosystem I has a reaction centre activated by light of wavelength 700 nm.
- Photosystem II has a reaction centre activated by light of wavelength 680 nm.

* Photophosphorylation - The light dependent stage of photosynthesis

In light conditions, photons are constantly hitting chlorophyll molecules in both PSI and PSII, exciting the electrons. If an electron is raised to a sufficiently high energy level it will leave the chlorophyll molecule completely. The excited electron can be picked up by an electron acceptor. This in turn results in the synthesis of ATP by one of the two processes:

• Cyclic photophosphorylation

Cyclic photophosphorylation involves only PSI and drives the production of ATP. When light hits a chlorophyll molecule in PSI, a light-excited electron leaves the molecule. It is taken up by an electron acceptor and passed directly along an electron transport chain to produce ATP. When an electron returns to the chlorophyll molecule in PSI, it can then be excited in the same way again.

• Non-cyclic photophosphorylation

A pair of electrons from chlorophyll is boosted to a higher energy level in PSII. They picked up by an electron acceptor and passed along an electron transport chain until it reaches PSI. Photons also hit PSI, so a pair of electrons are promoted to a higher energy level. The electrons from PSII replace these electrons. A molecule of nicotinamide adenine dinucleotide phosphate (NADP) picks up the two electrons from PSI and also 2 hydrogen ions. These hydrogen ions come from the photolysis of water.

→ Now the chlorophyll molecule in PSII is short of a pair of electrons. ~~The~~ Electrons come from photolysis of water to stabilise the chlorophyll molecule.

$*4OH^- - 4e^- \rightarrow O_2 + H_2O$

- $4e^-$ → last to chlorophyll
- $4OH^-$ → hydroxide ions left behind from the photolysis of water

* Once each PSII chlorophyll molecules recieve electrons, they are ready to be excited again when hit by a photon of light.

In summary,

→ ATP and $NADPH^+$ are produced and these are involved in the following step of reactions [light-independent stage]

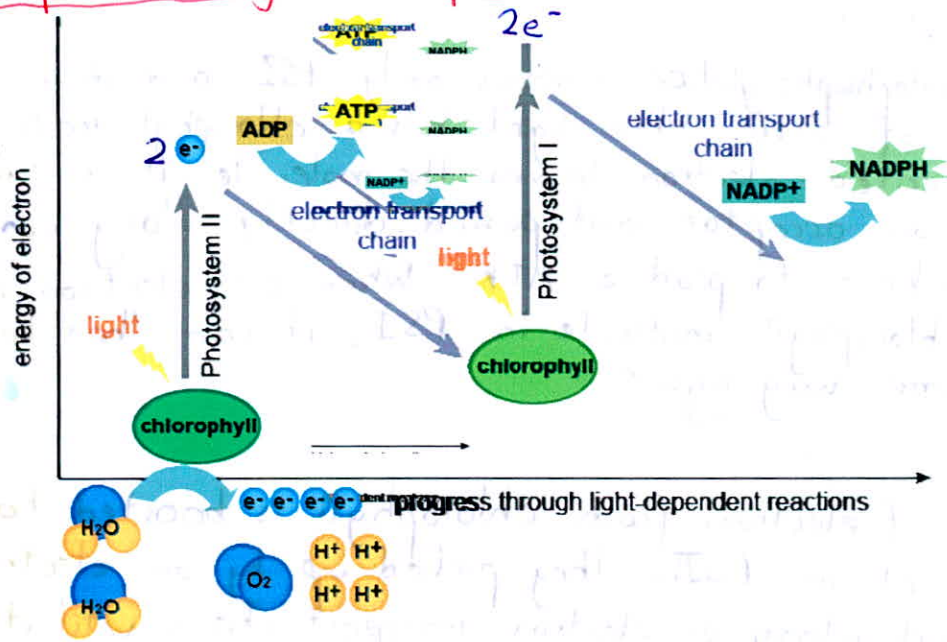
→ Oxygen gas is released as a waste product.

HSW – ATP

$$ADP + P_i \rightleftharpoons ATP$$

* Phosphorylation of ADP requires energy and hydrolysis of ATP provides an immediate energy supply of energy for biological processes.

Diagram for the light-dependent reactions



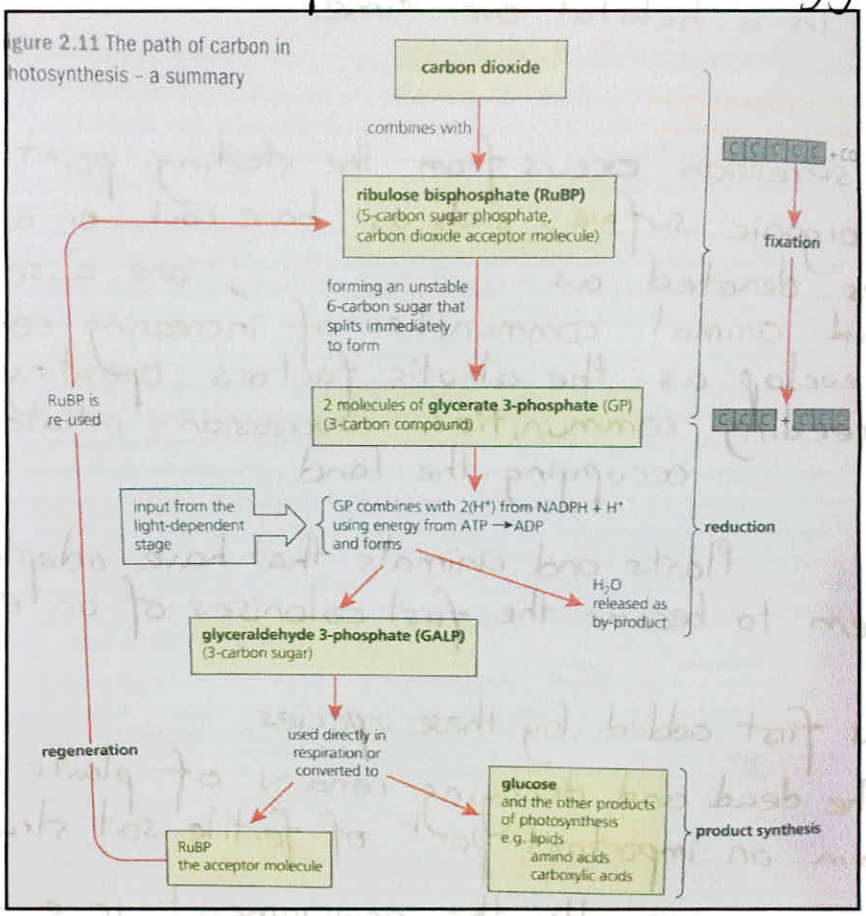
Note: Light-dependent reactions occur in the grana of chloroplasts.

The light-independent stage of photosynthesis

The light-independent stage of photosynthesis uses the reducing power (reduced NADP) and energy-supplying ATP produced by the light-independent stage. This stage consists of a series of reactions known as the Calvin cycle which take place in the stroma of the chloroplast.

In the first step, carbon dioxide from the air combines with the 5-carbon compound ribulose bisphosphate (RuBP), making it part of the photosynthetic reactions. This reaction is catalysed by the enzyme ribulose bisphosphate carboxylase/oxygenase (RUBISCO). The result of the reaction between RuBP and carbon dioxide is, in theory, a 6-carbon compound. It immediately splits to give two molecules of glycerate 3-phosphate (GP), a 3-carbon compound. GP is then reduced to form glyceraldehyde 3-phosphate (GALP), a 3-carbon sugar. The hydrogen for this reduction comes from reduced NADP and the energy required from ATP, both produced in the light-independent stage.

Much of the 3-carbon GALP passes through a series of steps to replace ribulose bisphosphate needed in the first step of the cycle. However, some of it is synthesised into the 6-carbon simple sugar glucose. Glucose is then used as the building blocks for more complex carbohydrates, proteins and lipids or in respiration to release energy.



igure 2.11 The path of carbon in hotosynthesis – a summary

Ecosystems

Terms

- **Habitat:** A habitat is the place where an organism lives.
- **Population:** A population is a group of organisms of the same species, living and breeding together in a habitat.
- **Community:** A community is all the populations of the different species of organisms living in a habitat at any one time.
- **Niche:** The role of an organism in the community. – Habitat nide – Food niche
- **Abiotic factors:** They are the non-living elements of the habitat of an organism
- **Biotic factors:** They are the living elements of a habitat which affect the ability of a group of organisms to survive there.

Changing ecosystems

The major biomes of the Earth have developed over thousands or even millions of years from original bare rock into the ecosystems of today. This has been brought about by succession.

Succession: Sequences of different ecological communities developing in a habitat over time.

Primary succession

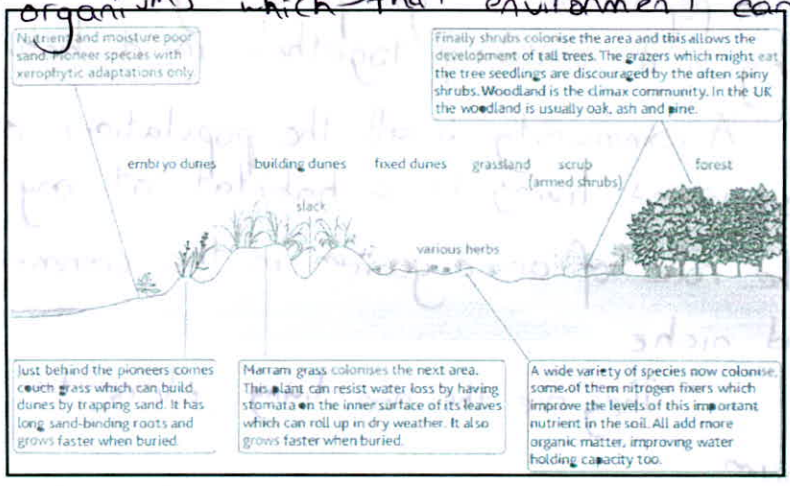
Primary succession occurs from the starting point of an empty inorganic surface, such as bare rock or a sand dune. The stages denoted as seral stages, are a series of plant and animal communities of increasing complexity which develop as the abiotic factors operating change with succeeding communities. Succession initiates with pioneer species occupying the land.

Pioneer species: Plants and animals that have adaptations to enable them to become the first colonisers of an empty habitat.

Humus is first added by these species.

Humus: The dead and decaying remains of plants and animals which form an important part of fertile soil structure.

→ Pioneer species alter the environment in a way that makes it an unsuitable home for them, but suitable for new species to establish. The new species often replace existing species. This continues until a stable community is reached. This is a climax community. A climax community is self-sustaining and usually the most productive group of organisms which that environment can support.


Nutrient and moisture poor sand. Pioneer species with xerophytic adaptations only.
Finally shrubs colonise the area and this allows the development of tall trees. The grazers which might eat the tree seedlings are discouraged by the often spiny shrubs. Woodland is the climax community. In the UK the woodland is usually oak, ash and pine.
embryo dunes
building dunes
fixed dunes
grassland
scrub (armed shrubs)
forest
slack
various herbs
Just behind the pioneers comes couch grass which can build dunes by trapping sand. It has long sand-binding roots and grows faster when buried.
Marram grass colonises the next area. This plant can resist water loss by having stomata on the inner surface of its leaves which can roll up in dry weather. It also grows faster when buried.
A wide variety of species now colonise, some of them nitrogen fixers which improve the levels of this important nutrient in the soil. All add more organic matter, improving water holding capacity too.

Secondary succession

Secondary succession is the evolution of an ecosystem from existing soil that is clear of vegetation. It occurs as rivers shift their courses, after fires and floods. The sequence of events is very similar to that seen in primary succession, but because the soil is already formed and contains seeds, roots and soil organisms, the numbers of plants and animals present right from the beginning of the succession are much higher and the climax community is reached much quicker.

Distribution and abundance

In any habitat a species occupies a specific niche determined by environmental conditions, biotic and abiotic factors, and the way the species uses the habitat (food, shelter, feeding times). The distribution and abundance are determined by these conditions. Changes in these conditions can therefore lead to changes in distribution and abundance.

• The effect of abiotic factors

Abiotic factors of a terrestrial habitat are of three types, relating to:

- climate: factors such as solar radiation, temperature, rainfall and wind.
- soil: factors such as parent rock, soil water and soil chemistry, and the mineral nutrients available. These are the edaphic factors.
- topography: factors such as slope, aspect of the land, and altitude.

Climatic factors

- Solar radiation: The amount of light found in a habitat has a direct effect on the numbers of organisms found there. Plants are dependent on light for photosynthesis. Animals are affected by light indirectly, as a result of distribution of plants.
- Temperature: For any particular organism, there is a range of temperatures within which it can grow and successfully reproduce. The temperature of the environment particularly affects the rate of enzyme-controlled reactions in plants and ectothermic animals. Many animals have evolved

behaviours and physiological features which enable them to cope.

– Wind and water currents: Wind has a direct effect on the habitat. Wind increases water and heat loss from the body and so adds to the environmental stress an organism has to cope with. In water currents, organisms have to cope with strong currents: flow with the current, be strong swimmers and resist the force of the water.

Edaphic factors

The structure of the soil on which organisms live and grow can affect various populations associated with it. Sand has a loose, shifting structure that allows very little to grow on it.

- Plant of the future – Marram grass

Marram grass has massive root and rhizome networks, so they not only reproduce successfully but also bind the sand together, which makes it more suited for colonisation by other species. Not only does marram have an extensive branching root network, but it is also well adapted to survive the physiological drought conditions. Marram grass fills the sandy, salt-resistant, dune-binding niche perfectly.

- The effect of biotic factors

The organisms of an ecosystem affect each other. Interactions between organisms known as biotic factors, are between members of the same species (intraspecific competition) and between the members of different species (interspecific competition). Of course, the impact of biotic factors depends upon the number of organisms present in relation to resources available within a given environment. So biotic factors are usually density dependent.

– Competition

- Plants compete for space, light and mineral nutrients.
- Animals compete for food, territory, shelter and a mate.

– Predation

A predator is an organism that feeds on other living species. Predators feed on their prey and the population of prey starts to decline. Meanwhile the well-fed predators breed more so their numbers increase. Eventually their food source starts to become scarce and some die. As their numbers decline the number of prey begins to rise and the cycle begins again.

– Parasitism and disease

Parasitism and disease are biotic factors which devastating effect on individuals. Diseased animals will be weakened and often do not reproduce successfully. Sick predators cannot hunt well, and diseased prey animals are more likely to be caught.

Parasites affect their hosts usually by feeding off the living body of their host and so weakening it.

* Parasites and infectious diseases spread more rapidly when there is a high population density, as individuals are in much closer proximity to each other.

Energy transfer in ecosystems

Energy within an organism can be used to produce more body tissue, that is to increase its biomass. Since the source of energy in most ecosystems is the Sun, the rate at which producers convert the Sun's energy into organic material will determine the flow of energy within those ecosystems.

Gross primary productivity (GPP): in plants is the rate at which energy is incorporated into the plants. It is measured in biomass/area/time. e.g $g\,C\,m^{-2}\,year$.

→ Plants use up to 25% of this accumulated energy for their own needs. Most importantly they respire, breaking down glucose to release energy in the form of ATP for use in metabolic processes. The rest of the energy is stored in their body tissues. This stored energy is known as the **net primary productivity (NPP)**.

$$NPP = GPP - \text{plant respiration}$$

The NPP of different ecosystems can be estimated. This productivity will depend on all the abiotic factors and biotic factors that affect plant growth within the ecosystems.

- **Food chains**

Although a food chain is a highly simplified model, it has helped us develop an understanding of energy flow through ecosystems.

producers → primary consumers → secondary consumers → tertiary consumers

Example question on NPP calculation

Q – Energy is transferred between trophic levels. If the producers lose 145×10^3 kJ m^{-2} $year^{-1}$ in respiration, calculate the percentage of net primary production (NPP) which is passed to primary consumers.

Data

Energy entering trophic level

- Producers : 180.0×10^3 kJ m^{-2} $year^{-1}$
- Primary consumers : 5.0×10^3 kJ m^{-2} $year^{-1}$

Answer

$$NPP = GPP - \text{plant respiration}$$
$$= 180.0 \times 10^3 - 145 \times 10^3$$
$$= 35 \times 10^3$$

$$\% \text{ efficiency} = \frac{5.0 \times 10^3}{35 \times 10^3} \times 100 = 14.3\%$$

Energy transfer to higher trophic levels

The energy in plant material is available to herbivores, but relatively little of it ends up as new animal material.

- Some energy is lost as undigested food in the faeces.
- Some energy is lost as heat released from respiration.
- Some is lost as chemical energy in metabolic waste products and heat energy in the urine of the animal

The energy used to make new animal biomass is known as **secondary production**.

Similar energy losses occur between animal trophic levels, herbivores to primary carnivores, and so on up the food chain. The proportion of energy used to make biomass compared with the energy available to an organism in the trophic level below is a measure of the efficiency of energy transfer.

The causes of such wide variation depend on many factors, including the effort required to find food, the digestibility of the food and the metabolic rate of the organism.

Energy transfer and food chain length

One of the main effects of the relatively inefficent transfer of energy through food chains and webs is to limit the number of trophic levels. At higher trophic levels, the organisms usually need to range over large distances, so, by the fourth or fifth trophic level it could take more energy to get food or a mate than is needed for growth and reproduction.

Global warming and climate change

The mechanism of the greenhouse effect

Greenhouse effect: Atmospheric warming caused by the absorption of reradiated solar energy by greenhouse gases.

Greenhouse gases reduce heat loss from the surface of the Earth. When radiation from the Sun reaches the Earth, some is reflected back into the space by the atmosphere. The key wavelength is infrared, the radiation we feel as heat. IR radiation that reaches the Earth's surface is of a fairly short wavelength. This is absorbed by the surface of the Earth and then radiated from the surface at a longer wavelength. Some of this radiation is absorbed and reradiated back to the Earth's surface by greenhouse gas molecules in the atmosphere. This maintains the temperature at the surface of the Earth at a higher level which makes life suitable.

Greenhouse gases:

- Carbon dioxide
- Methane
- Water vapour
- Oxides of nitrogen
- CFCs

* Both H_2O and CH_4 are naturally occuring as is CO_2.
* CH_4 is much more efficient at heat retention than CO_2, although not present in the same proportions.

Enhanced greenhouse effect?

Increases in the atmospheric concentrations of greenhouse gases will have inevitably enhanced the greenhouse effect.

In order to assess how the composition of the atmosphere changed over time current and historic levels of atmospheric CO_2 and CH_4 must be known. Furthermore, in order to establish a causal relationship between global warming and enhanced greenhouse effect, past temperatures must also be known.

Looking at the evidence

- Temperature records
- Records of carbon dioxide levels
- Pollen in peat bogs
- Dendrochronology

- Temperature records

We have data of measured temperatures only since the mid-1800s. Further temperatures are inferred from other data that can give an indication of the temperature but not an exact value. These other sources of data are called temperature proxies, and the **error lines** shown in grey on the graph below indicate the accuracy of these values. The black lines indicate the mean values.

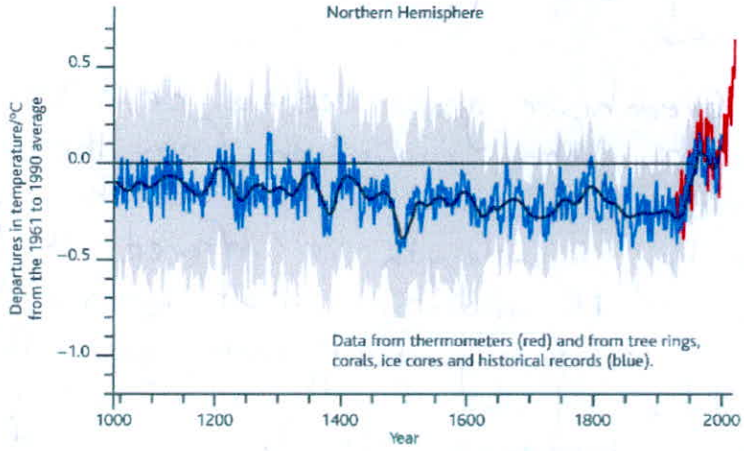


fig. 5.3.6 The IPCC 'hockey stick graph' published in 2001 uses data from a variety of sources to show how the temperature has changed over centuries. The term 'hockey stick' comes from the shape of the graph. Note that the grey is the error on each measurement, i.e. the range in which the real value is thought to lie, so we cannot actually be too accurate!

Temperature proxies include:

- Tree rings
- Corals
- Ice cores
- Peat bog data

- Ice cores

Scientists drill deep down into the ice and then analyse the air trapped in the different layers. Records of the oxygen isotopes in melted ice (O^{18} to O^{16}) reflect the air temperature at the time the ice layer was laid down.

Air trapped in ice when it was formed thousands of years ago can also be analysed. This gives information about CO_2 levels in the past.

- Dendrochronology

Dendrochronology is the dating of past events using tree ring growth. Trees increase in width as they get older by cell division of one particular layer in their trunks. When there is plenty of moisture and trees are growing quickly, these new cells are large. As conditions get more difficult, the new cells produced are smaller. The contrast between small cells at the end of one year and the large ones produced the next spring which give the appearance of the rings.

The problem with evidence from dendrochronology is that growth in trees is dependent on many factors, including the amount of sunshine, temperature, carbon dioxide levels and amount of rainfall. If the climate is warmer and wetter then tree rings are wider.

Many people questioned the validity of using tree-ring data to determine past temperature conditions. Data from coral reefs can be used to confirm evidence from trees, as the proportions of different isotopes taken up by the coral vary as the sea temperatures change and this gives another valuable proxy record of climate change.

- Peat bog data

Peat bogs are made of partly decomposed plant material. The peat is very acidic, cool and anaerobic, which prevents bacteria from decomposing organic material.

Pollen grains are preserved in peat bogs. By sampling at different levels in the peat we are sampling at different ages. Analysis of pollen can tell us which plants were growing and so what the climate was like when the peat was formed.

- Evidence for increasing levels of carbon dioxide

Scientists have found evidence for the increasing levels of carbon dioxide in the atmosphere in many different ways. Some of the most famous evidence comes from what is known as the Mauna Loa curve. The records show that the level of atmospheric carbon dioxide has increased from 315.98 ppmv in 1959 to 381.74 in 2006. The annual fluctuations in the levels of CO_2 seem to be the result of seasonal differences in the fixation of CO_2 by plants, as in temperate regions plants lose their leaves in winter and take up less CO_2.

The global warming debate

A lot of evidence from many studies now suggests a a clear correlation between the increase in temperature and carbon dioxide levels.

To say that there is a causal relationship we need some mechanism that explains how one factor changes the other. From our understanding of the greenhouse effect and because of the timing, a logical step is to consider that humans are responsible.

However, some scientists have proposed a mechanism where solar activity affects cloud formation and surface temperature. A much closer correlation is seen between solar activity and atmospheric temperature than it does between carbon dioxide concentrations and temperature. However IPCC decided that these activities should have resulted in cooling rather than warming.

+ Computer modelling

Any attempt to predict climate change in the future must rely on very complex computer models to extrapolate from what we know to what might happen.

Extrapolation: The practice of extending conclusions or graphical presentation beyond that shown by data to make predictions about future trends and patterns.

These models get better all the time but they are limited by lack of computing power, sufficient data and knowledge of how the climate functions. There are many factors that are very hard to predict, such as as rates of photosynthesis across the world, rates of carbon dioxide between the atmosphere and oceans and the effect of changing temperature on all of these.

- Limitations of extrapolation -

There are many limitations because not only it is impossible to tell the exact impact of carbon dioxide on global warming it is also impossible to predict the impact of global warming on particular aspects of the world climate. In addition, extrapolations from past data cannot take into account unknown factors in the future, including how current trends in use of resources and technologies may change.

Effects of global warming

- ## Risk of flooding

Antartic temperatures are increasing and billions of tonnes ice is braking away each year. Many scientists believe that the thinning of ice is a clear indication of global warming.

As ice melts, the volume of water in the seas and oceans of the world will increase, causing sea levels to rise. And as the water gets warmer, its volume increases, resulting in an even bigger impact on sea levels.

- ## Climate change

Rising temperatures affect weather and rainfall patterns. It is impossible to link any one event regarding weather to global warming, but statistical evidence suggests that there is an increase in extreme weather events linked to the rise in global temperatures.

- ## The effect on organisms

Temperature has an effect on enzyme activity which in turn affects the whole organism. A 10°C increase in temperature will double the rate of an enzyme-controlled reaction. However, there is an optimum temperature for many enzyme-controlled reactions and if the temperature increases beyond that point the enzyme starts to denature and the reaction rate falls. As a result, increasing temperature could have different effects on processes, including the rate of growth and reproduction.

- Effect on plants:

→ If plants grow faster they will take up more carbon dioxide and may therefore reduce atmospheric carbon dioxide levels.

→ In other places, temperature may exceed the optimum for some enzymes, and organisms there will die.

- Effect on animals:

Global warming appears to be affecting the onset of the seasons, affecting both life cycles and the distribution of species.

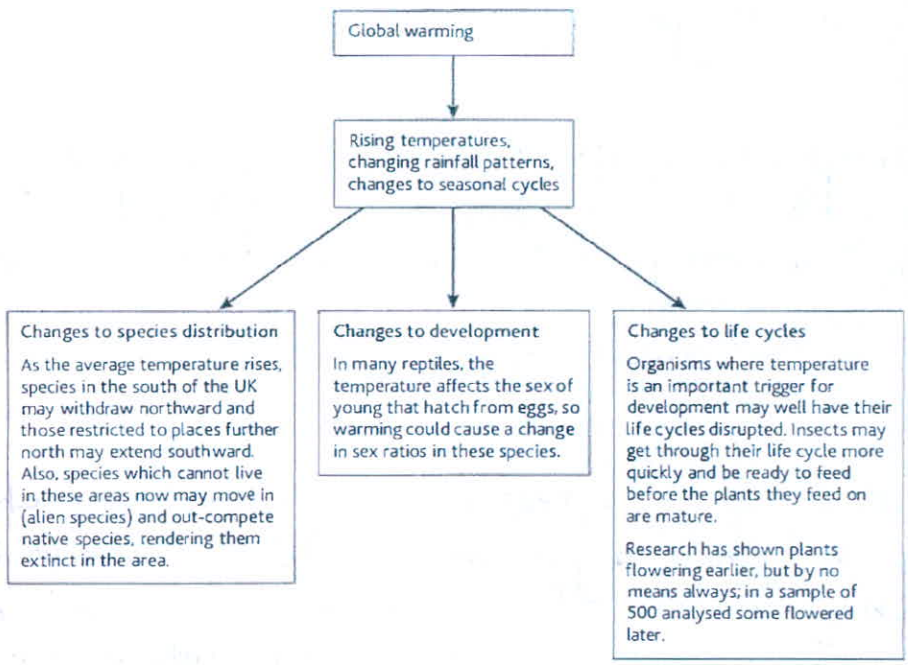
→ Insects become active earlier in warmth.

→ The breeding time is generally getting earlier.

• Changes in species distribution

A change in climate could affect the range of many organisms. Because most animals can move easily than plants, they can often survive change more easily. So as areas become warmer, some animals may be able to extend their ranges northwards while becoming extinct at the southern end. Others may be able to colonise a bigger area and that includes disease-carrying insects.

* In summary,


Global warming
Rising temperatures, changing rainfall patterns, changes to seasonal cycles
Changes to species distribution
As the average temperature rises, species in the south of the UK may withdraw northward and those restricted to places further north may extend southward. Also, species which cannot live in these areas now may move in (alien species) and out-compete native species, rendering them extinct in the area.
Changes to development
In many reptiles, the temperature affects the sex of young that hatch from eggs, so warming could cause a change in sex ratios in these species.
Changes to life cycles
Organisms where temperature is an important trigger for development may well have their life cycles disrupted. Insects may get through their life cycle more quickly and be ready to feed before the plants they feed on are mature.
Research has shown plants flowering earlier, but by no means always; in a sample of 500 analysed some flowered later.

What can be done?

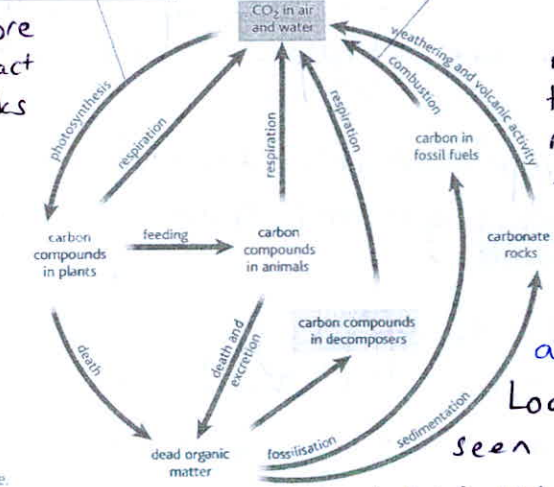
Understanding the carbon cycle can lead to methods to reduce atmospheric levels of carbon dioxide.

Plants take in CO_2 in photosynthesis, and trees store a lot of CO_2 as they gain size. Deforestation is thought to be an important cause of CO_2 increase in the air. The large-scale planting of new trees could reduce the amount of CO_2 in the atmosphere.

• Planting more trees which act as carbon sinks

One way of reducing CO_2 levels would be to grow plants to use as fuel. They would only release the CO_2 they had just taken in and so would be carbon neutral. However, chopping down rainforest to grow palms for oil releases more CO_2 than it takes in, and using corn to make ethanol for biofuel deprives people of food.

• Replacing fossil fuels by carbon-neutral biofuels



The carbon cycle in nature.

* It is clear that there are a number of inputs and outputs to and from the atmospheric reservoir of CO_2. Until recently, the two have been in balance but now it is clear that there is extra CO_2 being added to the atmosphere by human activity. (anthropogenic CO_2). Looking at the cycle it can be seen that there are a number of ways we could intervene to offset this.

Who decides?

Global warming is happening – few people dispute that – but how much is caused by human activities and what actions, if any, should be taken to reduce it are much more controversial issues.

→ The decisions about energy usage and carbon emissions are usually made by politicans, and they are influenced by many factors, such as their political perspective, as well as the scientific evidence. They are also influenced by pressure groups and lobbyists who are biased in their own interests. Environmental campainers and scientists are anxious that politicians tackle CO_2 emissions to reduce the impact of global warming. Many industrialists, particularly in the field of electricity generation and the petrochemical industry, have a vested interest in promoting alternative theories for global warming to avoid legislation that changes their industry.

Speciation and Evolution

Natural selection

Natural selection is the process by which the organisms best suited to a particular environment are most likely to survive and pass on their advantageous genetic characteristics to their offspring.

* Natural selection can lead to adaptation and evolution.

→ The individuals in a species are not identical, but show variations in their chatacteristics and each species has a gene pool.

- Gene pool: The total of all the different alleles in a population

→ Genetic diversity and a gene pool arise via:

- random assortment of paternal and natenal chromosomes in meiosis.
- crossing over: of segments of individual maternal and paternal handogous chromosomes that results in new combinations of genes on the chromosomes of the haploid gametes produced by meiosis.
- the random fusion of male and female gametes in sexual reprod-ction.

* Additionally, mutations can cause small changes in genes and they are a source of variation on which natural selection acts. Mutations can increase the size of the gene pool of a population by increasing the number of different alleles.

- Allele frequency: The proportion of one allele within a gene pool / population.

- Evolution: Evolution is the change in frequency of certain alleles in a gene pool over time due to natural selection.

Steps in evolution

- Genetic variation in population
- Mutation and/or meiosis as a source of genetic variation
- Selection pressure due to changing conditions
- Survival of the individuals with advantageous alleles
- Beneficial alleles passed on
- Change in allele frequency over population.

Speciation

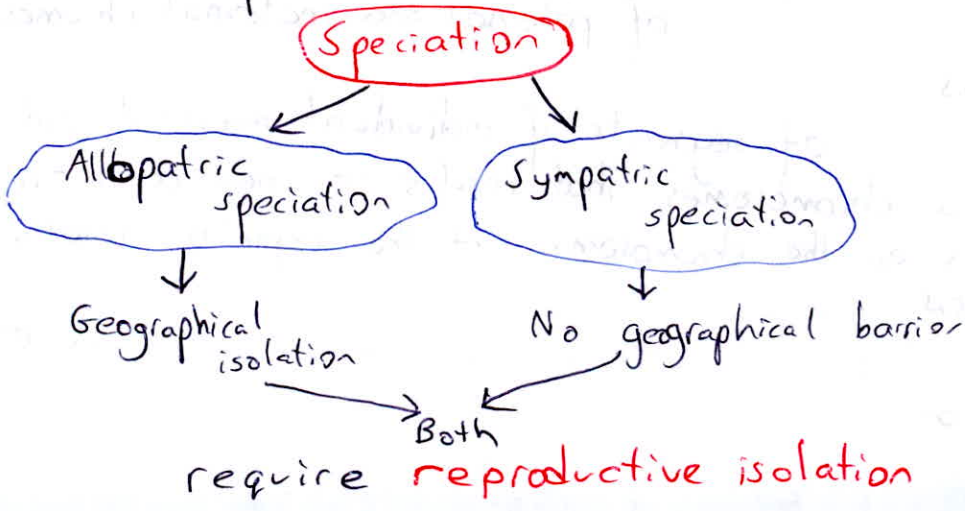
Species: A group of closly related organisms that are all potentially capable of interbreeding to produce fertile offspring.

or:

Species: A group of organisms where the genes can flow between individuals.

Therefore, two different species are present if the individuals of the populations cannot interbreed with each other.

→ As a result of random mutations, the variation in the DNA sequence between individuals of a species of animals or plants increases. Through natural selection this can lead to evolution and speciation.



Isolating mechanisms

For different species to evolve from one original species, different populations of the species usually have to become isolated from each other, so that mating, and therefore gene flow between them is restricted.

- **Allopatric speciation**

Allopatric speciation takes place when populations are physically separated in some way. It requires geographical isolation.

- **Sympatric speciation**

Sympatric speciation takes place when two populations are geographically still close together. Reproductive isolation is crucial to speciation and for sympatric speciation this occurs when fertilisation is prevented (prezygotic) or when the zygote fails or is unable to breed (postzygotic).

* Reproductive barriers

Prezygotic reprodutive barriers	Explanation
Habitat isolation	Populations occupy different habitats in the same area so do not meet to breed.
Temporal isolation	Species exist in the same area but are active for reproduction at different times.
Mechanical isolation	The reproductive organs no longer fit together.
Behavioural isolation	Populations do not respond to each other's reproductive displays.
Gametic isolation	Male and female gametes from two populations are simply incompatible with each other.
Postzygotic reproductive barriers	**Explanation**
Hybrid sterility	Healthy individuals produced from the mating of two different species cannot themselves reproduce.
Hybrid inviability	Individuals produced from the mating of two different species are not healthy and do not survive.

New evidence for the theory of evolution

Darwin's theory was very controversial in its day and still is for some people. There are now new types of evidence supporting the theory available to us:

- The DNA molecule is the same in all organisms. This supports Darwin's idea of descent from a common ancestor.
- DNA and proteins contain a record of genetic changes that have occured by random mutations over time, indicating gradual change within and between species. By studying DNA (genomics) and proteins (proteomics) these changes can be identified. Comparing the DNA or amino acid sequences in different species can show how closely related species are in evolutionary terms. The more similar the sequence, the more closely related the species.

- Assessing the speed of mutation in DNA has shown that species have evolved over vast periods of time, as Darwin thought.

Validating evidence

Any new evidence must be carefully studied before it can be accepted. The scientific process has three key aspects which try to ensure reliability and validity:

- dedicated scientific journals
- peer review
- scientific conferences

There are thousands of scientific journals published worldwide. Any research carried out must be published in at least one of these so it can be read by other scientists. However, before it even gets to this stage it has to undergo peer review. The editor of the journal sends a potential paper to two or three other scientists in the same area of work. They generally ask:

- Is the paper valid? (Are the conclusions based on good methods and are the data reliable?)
- Is the paper significant? (The paper must make a useful addition to the existing body of scientific knowledge)
- Is the paper original? (Or has somebody else done the same work?)

Only if the other scientists agree that the paper is all these things can it be published. Conferences allow scientists to set out their ideas in front of other people who work in the same field. The suggestions can be assessed but there is no need to go through the peer review process.

TOPIC 6: INFECTION, IMMUNITY AND FORENSICS

Decay and decomposition

Decay and decomposition is vital for the continuation of life on Earth. Plants need nutrients such as nitrogen, potassium, phosphorus and carbon to make biomass. These nutrients are locked into the tissues of the plants and any animals that might eat them. Once the plant or animal dies the nutrients can be released only through decay.

Micro-organisms are crucial to the decomposition process. The carbon cycle is a good example of how nutrients are recycled and how micro-organisms help. Bacteria and fungi produce a range of enzymes that are released on to the dead organic matter.

Indicator of time of death	How a forensic scientist uses the information
body temperature	Body temperature is usually 37 °C but the body begins to cool straight after death. During the first 24 hours after death the temperature of the body when it is found can be used to work out how long ago the person died.
degree of muscle contraction	After death, muscles usually totally relax and then stiffen. This stiffening is called rigor mortis. This happens within about 6–9 hours (depending on temperature). The stiffness occurs because muscle contraction relies on ATP, which cannot be made once respiration has stopped. So the muscles become fixed. The stiffness wears off again after about 36 hours in cooler conditions as the muscle tissue starts to break down.
extent of decomposition	Bodies usually follow a standard pattern of decay. Enzymes in the gut start to break down the wall of the gut and then the surrounding area. As cells die they release enzymes which help to break down tissues. The signs of decomposition, such as discoloration of the skin and gas formation, combined with information about environmental conditions allow time of death to be estimated.
forensic entomology	Determining the age of any insect maggots on the body allows the time the eggs were laid to be determined. This provides an estimate of time of death assuming any eggs were laid soon after death.
stage of succession	As a body decays, the populations of insects found on it change. There is a succession of species. The community of species present when the body is found allows the stage of succession to be determined and time of death estimated.

Putting all this information together can give the forensic scientist a very good estimate of time of death.

The nature of the genetic code

The genetic code has several important properties.

- Triplet code: With 20 amino acids and start and stop signals to code for and only four bases to do it, one base per amino acid will not do. Using three bases gives 64 codons which is more than enough.
- Non-overlapping: Each set of three bases forms one triplet. The triplets do not overlap, so no base from one triplet is part of another triplet, avoiding confusion about which amino acid is being coded for.
- Degenerate: Some amino acids have more than one codon. For example, there are four different codons for the amino acid proline. As long as the codon starts with CC the amino acid proline will be put into the polypeptide. The code is said to be degenerate. This offers some protection against mutation.

The process of protein synthesis

1. Transcription of mRNA takes place in the nucleus.

→ Transcription: The process by which the DNA nucleotide base sequence of a gene is copied into the RNA nucleotide base sequence in a molecule of messenger RNA (mRNA).

- The DNA double helix unwinds, and the hydrogen bonds holding the two strands together break. DNA helicase catalyses this reaction.
- One of the separated strands of DNA, the antisense strand, acts as a template for the formation of mRNA.
- Free RNA nucleotides present in the nucleus pair up with exposed nucleotides on the antisense strand.

→ Antisense strand: The polynucleotide chain in a DNA molecule that is always used in protein synthesis to determine the order of amino acids in a polypeptide

- Complementary base pairing ensures cytosine always pairs with guanine and uracil always pairs with adenine.
- RNA polymerase catalyses the formation of phosphodiester bonds between the RNA nucleotides, forming a molecule of messenger RNA.

2. mRNA leaves the nucleus through nuclear pores.

3. mRNA associates with a ribosome.

→ Ribosomal RNA makes up about 50% of the structure of a ribosome and is the most common form of RNA found in cells. It is made in the nucleus, under the control of the nucleoli, and then moves out into the cytoplasm where it binds with proteins to form ribosomes. Their job is to hold together the mRNA, tRNA and the enzymes controlling the process of protein synthesis.

4. tRNA molecules are attached to specific amino acid.

- Amino acids are attached to their tRNA by an enzyme. These enzymes are specific to the particular amino acids to be used in protein synthesis. The specificity of the enzymes is a way of ensuring the correct amino acids are used in the right sequence.

5. tRNA molecules transport amino acids to the ribosome.

6. Translation takes place at the ribosome.

- The ribosome starts reading the mRNA at the start codon (AUG). This codes for the amino acid methionine.
- The tRNA lines up its anticodon alongside a complementary codon in the mRNA.
- Hydrogen bonds between the two bind the tRNA in place to the ribosome while enzymes link the amino acids together by peptide bonds. This continues until the stop codon.

Note: All newly formed polypeptides start with methionine, because of the nature of the start codon. However, in many cases this first amino acid is removed by enzymes before the polypeptide becomes part of an active protein.

Post-transcriptional modification of messenger RNA

It was originally thought that each gene coded for one protein. We now know that this is not correct. The RNA which is transcribed from the DNA is now referred to as pre-mRNA. It contains RNA copied from all the DNA in the gene, including nonsense sections which are not used to code for the protein. These areas are known as introns. The rest of the RNA is a copy of the areas of the DNA which code for the polypeptide chains — these areas are known as exons. So when the mRNA is first transcribed it is not quite finished.

A number of processes take place before it lines up on the ribosomes, such as capping the ends of RNA strand, so it is not attacked by enzymes, and the removal of introns The remaining exons are joined together to form a single long molecule during RNA splicing
This is carried out by large enzyme complexes known as spliceosomes. Sometimes some exons are removed as well, so that the code on the final mRNA is clearly different from the code on the DNA.

Because strands of mRNA transcribed from the same bit of DNA may not be the same after these processes are complete, they may code for polypeptide chains containing slightly different amino acids, which in turn produce different proteins.

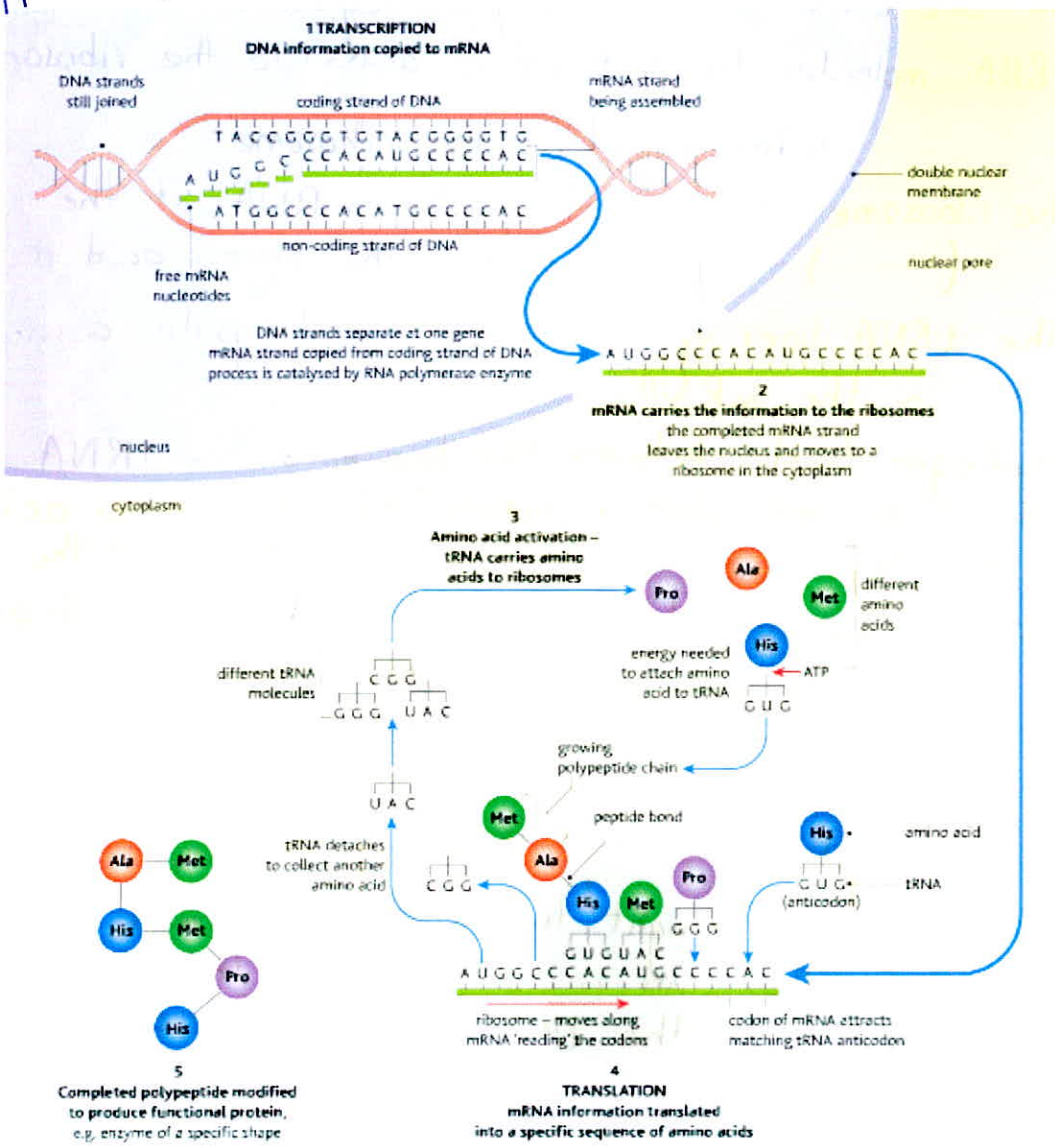

1 TRANSCRIPTION
DNA information copied to mRNA
DNA strands still joined
coding strand of DNA
mRNA strand being assembled
T A C C G G G T G T A C G G G G T G
A U G G C C C A C A U G C C C C A C
A T G G C C C A C A T G C C C C A C
non-coding strand of DNA
double nuclear membrane
nuclear pore
free mRNA nucleotides
DNA strands separate at one gene
mRNA strand copied from coding strand of DNA
process is catalysed by RNA polymerase enzyme
A U G G C C C A C A U G C C C C A C
2
mRNA carries the information to the ribosomes
the completed mRNA strand leaves the nucleus and moves to a ribosome in the cytoplasm
nucleus
cytoplasm
3
Amino acid activation – tRNA carries amino acids to ribosomes
Pro
Ala
Met
different amino acids
His
energy needed to attach amino acid to tRNA
ATP
different tRNA molecules
C G G
G G G
U A C
G U G
growing polypeptide chain
U A C
Met
Ala
peptide bond
tRNA detaches to collect another amino acid
C G G
His
Met
Pro
G G G
G U G U A C
A U G G C C C A C A U G C C C C A C
His
amino acid
tRNA
C U G
(anticodon)
ribosome – moves along mRNA 'reading' the codons
codon of mRNA attracts matching tRNA anticodon
Ala
Met
His
Met
Pro
His
5
Completed polypeptide modified to produce functional protein, e.g. enzyme of a specific shape
4
TRANSLATION
mRNA information translated into a specific sequence of amino acids

Fig. E.1.9 Protein synthesis is the way in which the information held in the sequence of bases in a gene is translated into a sequence of amino acids in a polypeptide chain

DNA profiling

DNA profiling relies on the fact that, apart from identical twins, every person's DNA is unique. A large amount of the DNA does not code for proteins. The non-coding blocks are called introns and are inherited in the same way as genes within the coding regions (exons).

Within introns, short DNA sequences are repeated many times. The sequences of repeated bases are known as short tandem repeats (STRs) or satellites.

The same STRs occur at the same locus on both chromosomes of a homologous pair. However, the number of times they are repeated on each of the homologous chromosomes can be different. The number of repeats at a locus also varies between individuals.

There is a large amount of variation in the number of repeats at each locus. These facts combined mean that two individuals are highly unlikely to have the same combination of STRs. It is important feature that enables scientists to create a virtually unique DNA profile.

* DNA profiling is used for identification and determining genetic relationships between organisms.

→ Short tandem repeats / satellites: In eukaryotes, these are regions of non-coding DNA that contain a particular sequence of nucleotide bases repeated many times over. The number of repeats at a particular locus is unique so can be used as a genetic marker.

The steps involved in DNA profiling

- Obtaining the DNA

– Extracting DNA from plant material

The tissue sample is physically broken down in a buffer solution that includes a salt and a detergent to disrupt the cell membranes. The small suspended particles, including the DNA, are separated from the rest of the cell debris by filtering or centrifuging. Protease enzymes are incubated with the suspension to remove proteins, and then cold ethanol is added to precipitate out the DNA. Several stages of washing the DNA in a buffer solution then follow.

- Creating the fragments

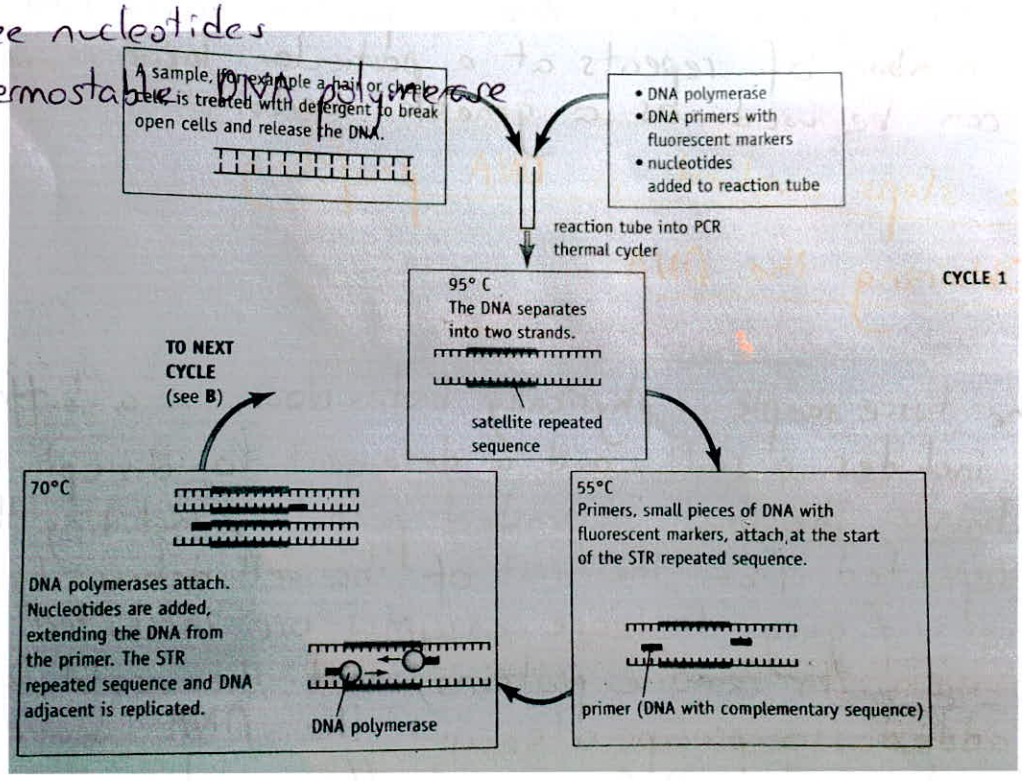
The strands of DNA from a sample are chopped up using special enzymes known as restriction endonucleases. These enzymes cut the DNA at particular points in the intron sequences. There are many different restriction enzymes, each type cutting a DNA molecule into fragments at different sites / specific base sequences known as recognition sites.

• Polymerase Chain Reaction (PCR)

The PCR is used to amplify target DNA sequences that are present within a DNA source. By this process, a large number of copies of a fragment is produced. The technique involves mixing DNA containing the target sequence with a mixture of reagents in a plastic PCR tube and placing the tube in a machine called a thermal cycler.

The reagents include:

- primers – A short strand of nucleotides with a base sequence that is complementary to the short base sequence at the beginning of a strand of DNA to be copied. Primers are used as a starting point for the action of DNA polymerase, both in the semi-conservative replication of DNA and in the PCR.
- free nucleotides
- thermostable DNA polymerase


A sample, for example a hair or cheek cell, is treated with detergent to break open cells and release the DNA.
• DNA polymerase
• DNA primers with fluorescent markers
• nucleotides added to reaction tube
reaction tube into PCR thermal cycler
CYCLE 1
95° C
The DNA separates into two strands.
satellite repeated sequence
TO NEXT CYCLE (see B)
55°C
Primers, small pieces of DNA with fluorescent markers, attach at the start of the STR repeated sequence.
primer (DNA with complementary sequence)
70°C
DNA polymerases attach. Nucleotides are added, extending the DNA from the primer. The STR repeated sequence and DNA adjacent is replicated.
DNA polymerase

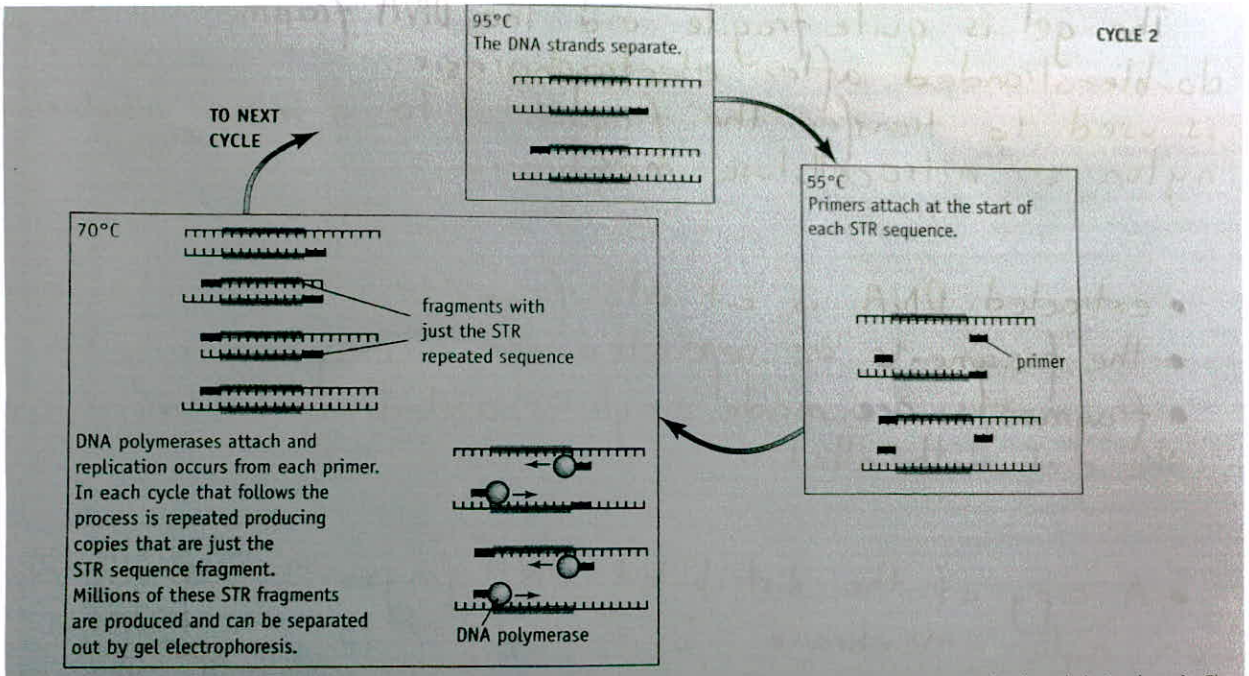

95°C
The DNA strands separate.
CYCLE 2
TO NEXT CYCLE
55°C
Primers attach at the start of each STR sequence.
primer
70°C
fragments with just the STR repeated sequence
DNA polymerases attach and replication occurs from each primer. In each cycle that follows the process is repeated producing copies that are just the STR sequence fragment. Millions of these STR fragments are produced and can be separated out by gel electrophoresis.
DNA polymerase

Figure 6.11 The polymerase chain reaction is used to multiply DNA samples to produce sufficient DNA for separation by gel electrophoresis. The sample goes through many cycles of temperature change, and **A** and **B** show what happens in the first two cycles. The exact temperatures used will depend on which species the DNA comes from. The whole cycle is repeated 25–30 times, taking about three hours and producing about 30 million copies of the DNA. 28 cycles are used for standard DNA profiling, 32 cycles are used when the DNA is not visible to the naked eye.

- Gel electrophoresis – Separating the fragments

– DNA fragments produced by restriction enzymes or PCR can be separated by gel electrophoresis according to their size.
– The DNA is placed on a gel of agarose or polyacrylamide.
– The gel is submerged in a buffer solution, and connected to electrodes that produce a potential difference across the gel.
– The negatively charged fragments migrate through the gel according to their overall charge and size.
– Smaller fragments, with smaller numbers of repeat sequences, travel faster. In a given time, smaller fragments end up closer to the positive electrode.
– A reference sample with fragments of known length may be added to the gel.

• Visualising the fragments

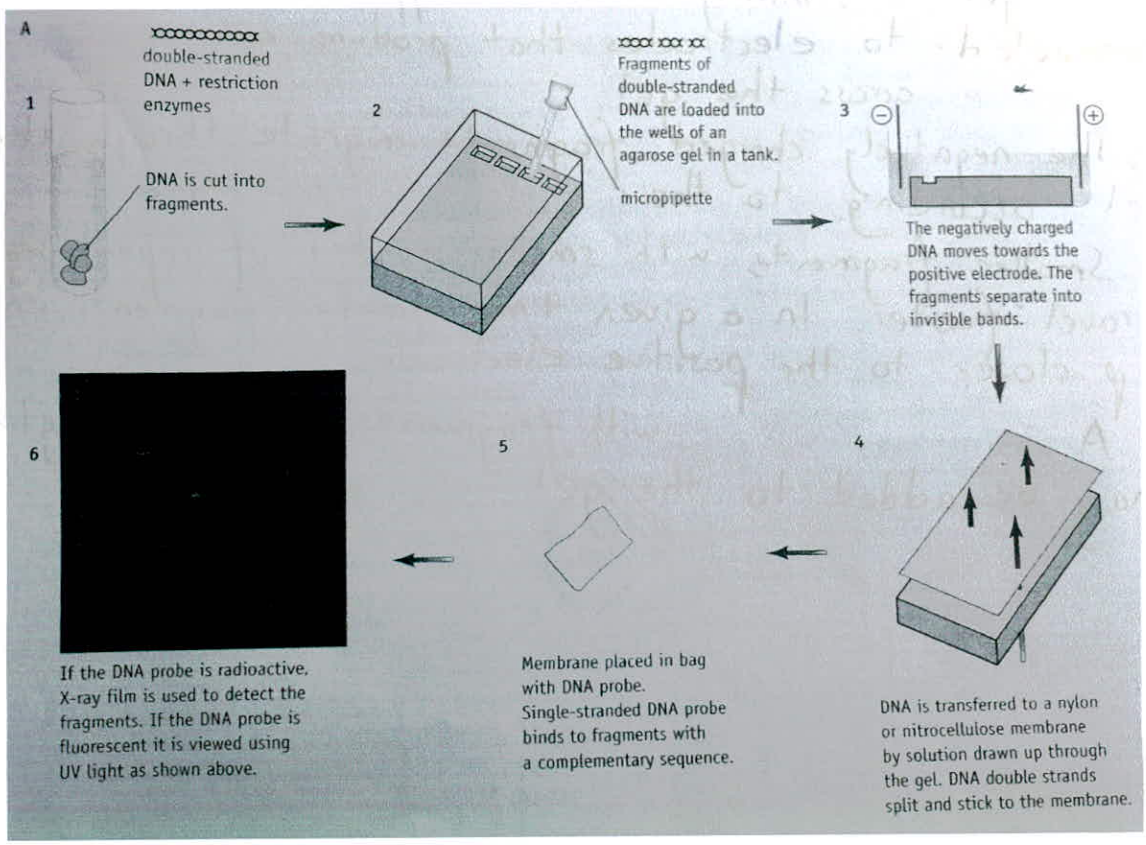
The gel is quite fragile, and the DNA fragments are double-stranded after electrophoresis. Southern blotting is used to transfer the fragments to a more resilient nylon or nitrocellulose membrane.

→ Southern blotting

- extracted DNA is cut into fragments with restriction enzyme
- the fragments are separated on electrophoresis gel
- fragments are made single-stranded by treatment of the gel with alkali.

Then,

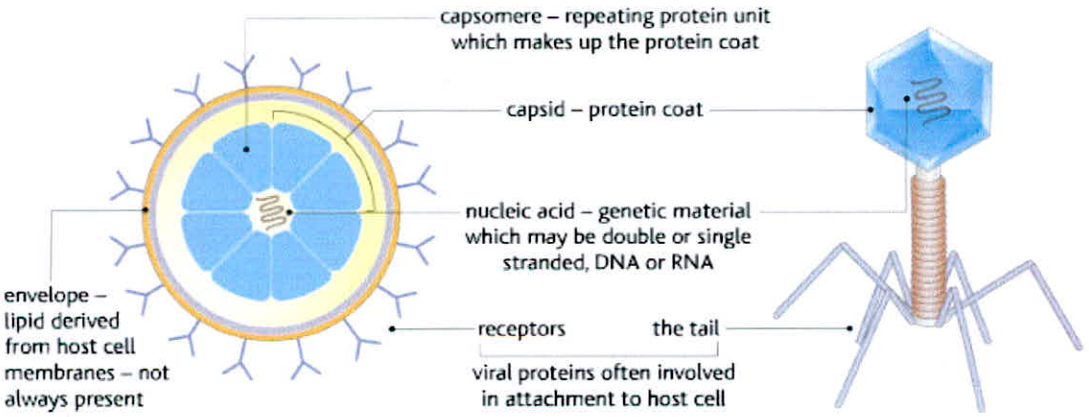
- A copy of the distributed DNA fragments is produced on nylon membrane.
- Heat treatment of the nylon membrane binds the DNA copies to it.
- Selected, radioactively labelled DNA probes are added to bind to particular bands of DNA
- Nylon membrane is now overlayed with X-ray film which is selectively 'fogged' by emission from the retained labelled probes.
- X-ray film is developed, showing up the positions of the bands to which probes are attached.


A
double-stranded DNA + restriction enzymes
1
DNA is cut into fragments.
2
Fragments of double-stranded DNA are loaded into the wells of an agarose gel in a tank.
micropipette
3
The negatively charged DNA moves towards the positive electrode. The fragments separate into invisible bands.
4
DNA is transferred to a nylon or nitrocellulose membrane by solution drawn up through the gel. DNA double strands split and stick to the membrane.
5
Membrane placed in bag with DNA probe. Single-stranded DNA probe binds to fragments with a complementary sequence.
6
If the DNA probe is radioactive, X-ray film is used to detect the fragments. If the DNA probe is fluorescent it is viewed using UV light as shown above.

Microorganisms and disease

Viruses are the smallest of all the microorganisms. Since viruses take over living cells to reproduce, they all cause damage and disease of some sort. They can withstand drying and long periods of storage while maintaining their ability to infect cells.

+ The structure of viruses


capsomere – repeating protein unit which makes up the protein coat
capsid – protein coat
nucleic acid – genetic material which may be double or single stranded, DNA or RNA
envelope – lipid derived from host cell membranes – not always present
receptors
the tail
viral proteins often involved in attachment to host cell

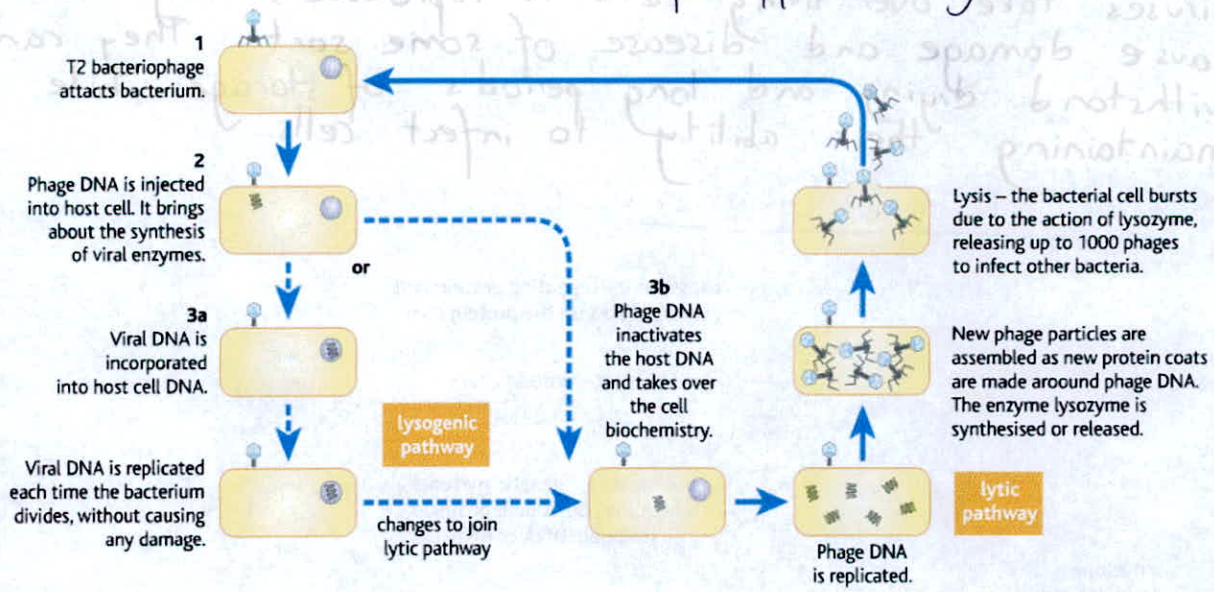
The protein coat or capsid is made up of simple repeating protein units known as capsomeres, arranged in different ways. In some viruses the genetic material and protein coat are covered by a lipid envelope, produced from the host cell. The presence of the envelope makes it easier for the viruses to pass from cell to cell, but it does make them vulnerable to substances which will dissolve the lipid membrane.

Viral genetic material can be DNA or RNA, and the nucleic acid is sometimes double stranded and sometimes single. Viral DNA acts directly as a template for both new viral DNA and for the mRNAs needed to induce synthesis of viral proteins. Bacteriophages in an example for such viruses. Viral RNA, however, directs the synthesis of a special enzyme called reverse transcriptase which proceeds to make DNA molecules corresponding to the viral genome. This DNA is used as a template for new viral proteins and ultimately a new viral RNA genome.

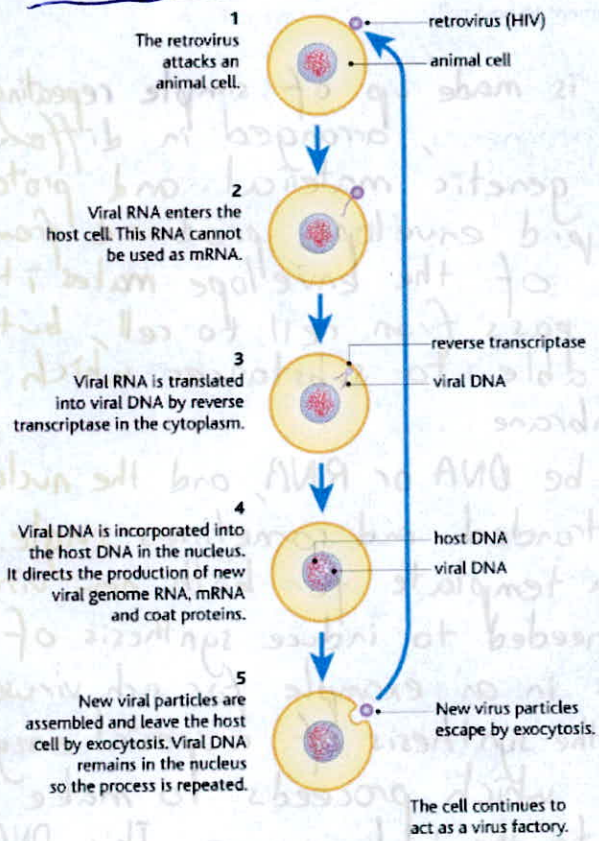
Viruses attach to their host cells by means of antigens known as virus attachment particles (VAPs) which target proteins in the host cell surface membrane. Because they respond to particular molecules of the host cell surface, viruses are often quite specific in the tissue they attack.

– Virus life cycles

Viruses reproduce only within the cells of a body. They attack their host cells in a number of different ways.


1
T2 bacteriophage attacts bacterium.
2
Phage DNA is injected into host cell. It brings about the synthesis of viral enzymes.
or
3a
Viral DNA is incorporated into host cell DNA.
Viral DNA is replicated each time the bacterium divides, without causing any damage.
lysogenic pathway
changes to join lytic pathway
3b
Phage DNA inactivates the host DNA and takes over the cell biochemistry.
Phage DNA is replicated.
New phage particles are assembled as new protein coats are made aroound phage DNA. The enzyme lysozyme is synthesised or released.
Lysis – the bacterial cell bursts due to the action of lysozyme, releasing up to 1000 phages to infect other bacteria.
lytic pathway

*Retroviruses


1
The retrovirus attacks an animal cell.
retrovirus (HIV)
animal cell
2
Viral RNA enters the host cell. This RNA cannot be used as mRNA.
3
Viral RNA is translated into viral DNA by reverse transcriptase in the cytoplasm.
reverse transcriptase
viral DNA
4
Viral DNA is incorporated into the host DNA in the nucleus. It directs the production of new viral genome RNA, mRNA and coat proteins.
host DNA
viral DNA
5
New viral particles are assembled and leave the host cell by exocytosis. Viral DNA remains in the nucleus so the process is repeated.
New virus particles escape by exocytosis.
The cell continues to act as a virus factory.

Retroviruses (including the HIV virus that causes AIDS) have a rather different and complex life cycle. Their genetic material is viral RNA. This cannot be used as mRNA but is translated into DNA by the specific enzyme reverse transcriptase in the cytoplasm of the cell. This viral DNA passes into the nucleus of the host cell where it is inserted into the host DNA. Host transcriptase enzymes then make viral mRNA and new viral genome RNA. New viral material is synthesised.

+ The structure of Bacteria

- All bacterial cells have a cell wall. It prevents the cell swelling and bursting.
- Bacteria have no mitochondria so the cell membrane is also the site of some of the respiratory enzymes. In some bacterial cells the membrane shows infoldings known as mesosomes.
- Some bacteria have a capsule around their cell walls. It protects the bacterium from phagocytosis by white blood cells. It also covers the cell markers on the cell membrane which identify the cell. So a capsule can make it easier for a bacterium to pathogenic because it is not identified by the host's immune system.
- Some bacteria have thread-like protein projections from their surface called pili.
- Some bacteria can move themselves using flagella.
- The genetic material consists of a single length of circular DNA lying free in the cytoplasm.
- Some bacterial cells also contain one or more much smaller circles of DNA known as plasmids.

Differences in the structure of Bacteria and viruses

Bacteria have a prokaryotic cellular structure with organelles but viruses do not.

Bacteria	Viruses
Cell surface membrane, cytoplasm, cell wall, ribosomes, plasmids and sometimes mesosomes, flagellum and pili.	No cell wall, cell surface membrane, cytoplasm or organelles. Nucleic acid enclosed in protein coat.
Circular strand of DNA is the genetic material.	DNA or RNA can be the genetic material.
Can live independently	Must have a living organism as host.
Average diameter 0.5–5μm	20–400nm, wide range of sizes and shapes.
Often have mucus-based cuter capsule.	May have outer membrane of host cell surface membrane, but containing glycoproteins from the virus.

Invading the body

For any disease to be passed on, the pathogen needs to get inside the body of the new host. There are a number of different ways to get in. The body openings - eyes, nose, mouth, ears, anus and urinogenital openings - provide relatively easy access. Pathogens are transmitted in a variety of ways:

- Vectors: A living organism that transmits infection from one host to another is known as a vector.
- Fomites: Fomites are inanimate objects that carry pathogens from one host to another.
- Direct contact: Many skin diseases and sexual diseases are transmitted via direct contact.
- Inhalation: Droplets expelled from the body by sneezing, coughing or simply by talking contain pathogens and may infect other people.
- Ingestion: Many of the pathogens that cause gut diseases are transmitted by contaminated food or drink.
- Inoculation: A pathogen can be inoculated into the body directly through a break in the skin. This transmission might be via an injury from contaminated medical instruments or shared needles for drug abuse.

Barriers to entry

- Eyes - tears contain the enzyme lyzozyme which helps to digest microbes.
- Internal tubes and tracts - Epithelial layers produce mucus, a sticky substance that traps microorganisms. Mucus contains lysozymes, enzymes capable of destroying microbial cell walls. These enzymes are particularly effective against Gram-positive bacteria, breaking down the cross-linkages in the peptidoglycans in the bacterial cell wall.
- Gastrointestinal tract - Acid in the stomach helps to protect against any microbes which are eaten. In addition the gut has its own bacteria. These compete with pathogens for food and space which helps to protect us. The harmless bacteria also excrete lactic acid which deters pathogens.

- Skin - the skin is a tough barrier and usually only allows pathogens to enter if it is cut. As an additional line of defence the skin has its own microbes. These live naturally on the skin and out-compete pathogens. Sebum is an oily fluid which is made by the skin and can also kill microbes.

Non-specific responses to infection

Once pathogens get inside your body tissues, other responses rather than physical barriers come into play. Some of these responses are non-specific, others are specific to particular pathogens. The non-specific responses recognise the difference between self and non-self and react against anything that is non-self.

- How do cells recognise each other?

Protruding from the outer surface of the cell surface membrane are many proteins, in particular glycoproteins which are protein molecules with a carbohydrate component. These chains of sugar molecules can be varied, and they seem to be important in cell recognition in several ways.

- Inflammation

The inflammatory response involves a number of stages. Special cells called mast cells are found in the connective tissue below the skin and around blood vessels. When this tissue is damaged, mast cells along with damaged white blood cells release chemicals known as histamines. These histamines cause the blood vessels in the area, particularly arterioles, to dilate causing local heat and redness. The locally raised temperature reduces the effectiveness of pathogen reproduction in the area. The histamines also make the walls of the capillaries leaky as the cells forming the walls separate slightly. As a result fluid including plasma, white blood cells and antibodies is forced out of the capillaries causing swelling.

- **Lysozyme action**

Lysozyme is an enzyme found in tears, sweat and the nose. It destroys bacteria by breaking down the bacterial cell walls.

- **Phagocytosis**

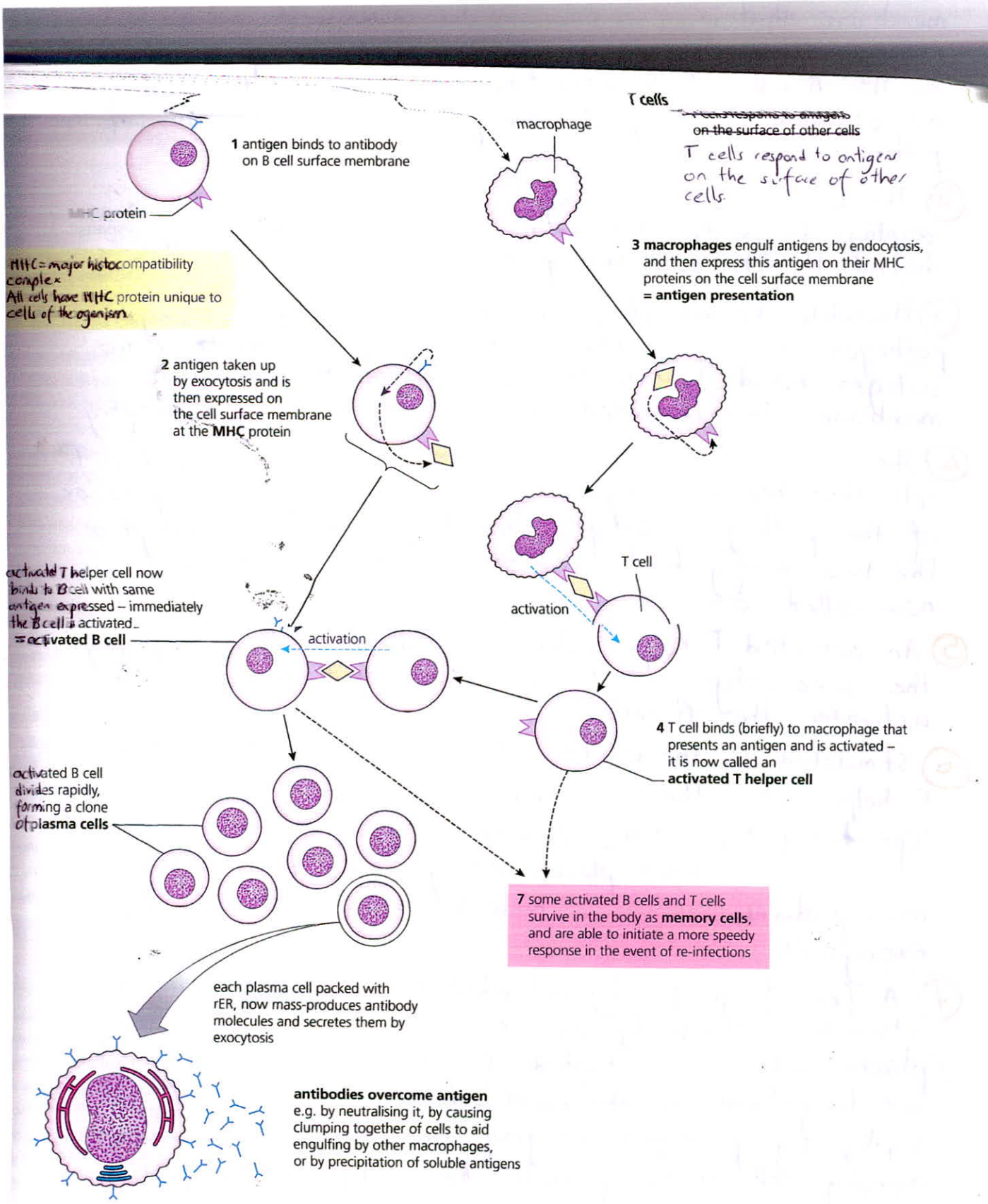
It involves white blood cells. There are two main groups of white blood cells, the granulocytes which have granules that can be stained in their cytoplasm, and the agranulocytes which have no granules. Phagocyte is a general term used to describe white blood cells which engulf and digest pathogens and any other foreign material in the blood and tissues.

There are two main types of phagocytes - neutrophils which are granulocytes and make up 70% of the white cells, and macrophages which are agranulocytes and make up about 5%.

- **Interferons**

Interferons are proteins that inhibit viral replication within the cells. An interferon diffuses from the cell where it is made into the surrounding cells. It binds to receptors in the surface membranes of uninfected cells, stimulating a pathway which makes the cells resistant to infection by viruses by preventing viruses reproducing.

Specific response to infection


T cells
~~T cells respond to antigens on the surface of other cells~~
T cells respond to antigen on the surface of other cells
macrophage
1 antigen binds to antibody on B cell surface membrane
MHC protein
MHC = major histocompatibility complex
All cells have MHC protein unique to cells of the organism
3 **macrophages** engulf antigens by endocytosis, and then express this antigen on their MHC proteins on the cell surface membrane
= **antigen presentation**
2 antigen taken up by exocytosis and is then expressed on the cell surface membrane at the **MHC** protein
activated T helper cell now binds to B cell with same antigen expressed – immediately the B cell is activated
= **activated B cell**
activation
T cell
activation
4 T cell binds (briefly) to macrophage that presents an antigen and is activated – it is now called an **activated T helper cell**
activated B cell divides rapidly, forming a clone of **plasma cells**
7 some activated B cells and T cells survive in the body as **memory cells**, and are able to initiate a more speedy response in the event of re-infections
each plasma cell packed with rER, now mass-produces antibody molecules and secretes them by exocytosis
antibodies overcome antigen
e.g. by neutralising it, by causing clumping together of cells to aid engulfing by other macrophages, or by precipitation of soluble antigens

ure 5.9 The steps involved in antibody release

Steps

1. A pathogen enters the body; its surface has non-self antigens on it. Completely at random, this pathogen collides with a B cell that has an antigen receptor on its surface membrane that is complementary to a non-self antigen on the pathogen. The antigen binds to the antigen-receptor molecule on the B cell. At the same time, other cells of the pathogen are attacked by non-specific macrophages that engulf cells of the pathogen.

2. The B cell engulfs the antigen and digests it. The B cells then displays fragments of the antigen on its cell surface membrane, bound to its own MHC proteins.

3. Meanwhile, the macrophage also digests the antigen-carrying pathogen it has engulfed. It too displays fragments of the antigen bound to the MHC proteins on its cell surface membrane. This is called antigen presentation by a macrophage.

4. The antigen-presenting macrophage comes into contact with a T cell that has an antigen-receptor protein complementary to one of the pathogen's antigens now displayed on the macrophage. The two briefly bind. This activates the T cell, which is now called an activated T helper cell.

5. An activated T helper cells now binds to a B cell displaying the same antigen on its cell surface membrane. This in turn activates the B cell.

6. Stimulated by the secretion of cytokines from the activated T helper cell, the activated B cell immediately divides very repeatedly by mitosis forming a clone of cells called plasma cells. Each plasma cell packed with rER, now mass-produces antibody molecules and secretes them by exocytosis.

7. A few of specifically activated B cells and T cells are retained in the body as memory cells. In contrast to plasma cells and activated T cells, these memory cells are long-lived. In the event of a re-infection of the body by pathogens carrying the same antigen, these memory cells make possible the early and effective response.

Developing immunity

- Active immunity

1-) Natural active immunity

Exposed to antigen by getting the disease. The body produces memory cells which make it immune to disease in the future.

2-) Artificial active immunity

The injection of dead or weakened disease organisms toxins or antigen fragments means that the body is exposed to the antigen and produces memory cells.

- Passive immunity

1-) Natural passive immunity

A mother's antibodies cross the placenta and are also found in breast milk. These antibodies can protect against any invading pathogen that the mother has encountered.

2-) Artificial passive immunity

Injected with antibodies that can provide immediate protection against the invading pathogen they are specific for.

* We can also use antibiotics to fight bacterial infections.

→ When an antibiotic is taken, it may have one of two different effects. It may be bacteriostatic, which means that the antibiotic or the dose completely inhibits the growth of the microorganism. This level of treatment is usually sufficient for the majority of everyday infections because, combined with the actions of our immune system, it will ensure that the pathogen will be completely destroyed. However, sometimes a particular drug, or the dose of a drug given, will be bacteriocidal. This means it will destroy almost all of the pathogens present. This type of treatment is particularly important in severe and dangerous infections.

The Evolutionary race

There is a constant evolutionary race between pathogens and us, their hosts. We keep developing new medicines and bacteria keep evolving resistance to these drugs. An antibiotic is effective only if the microorganism has a binding site for the drug and the metabolic process or biochemical pathway that the antibiotic interferes with. However, during bacterial reproduction there is always the chance that a mutation occurs, and some mutations might help the microorganism resists the effects of the antibiotic, such as by making the cell wall impermeable to the drug. Mutations like this will be selected for when the antibiotic is used, and the bacterial population will become increasingly resistant to the drug. Mutations can also result in new biochemical pathways, or switch on or acquire a gene for the production of an antibiotic-destroying enzyme.

Widespread use of antibiotics accelerates this process. As different antibiotics are used to tackle increasing resistance, this just increases the selection for bacteria that are resistant to all of them. This evolutionary race is creating what are known as **superbugs**.

The only way to prevent this trend continuing is to reduce the **selection pressure** for resistance by using antibiotics sparingly, only when they are strictly necessary, and to use a few different antibiotics as possible, holding some in reserve for use only when all else has failed.

Hospital acquired infections

Hospital code of practice	How it helps to stop antibiotic resistance
only use antibiotics when needed and ensure course of treatment is completed	reduces selection pressure on organisms and destroys all bacteria causing infection
isolating patients with resistant diseases	prevents transmission of resistant bacteria between patients
good hygiene encouraged, including hand washing and bans on wearing of jewellery, ties and long sleeved shirts	prevents the spread of infection and cuts down on the number of places that may harbour pathogens
screening of patients coming into hospital	a person may be infected without showing symptoms; this can be detected and they can be isolated and treated

Mutations help some bacteria to become resistant to antibiotics which result in problems with antibiotic-resistant infections in hospitals. Hospitals try to combat this using the codes in the table above.

Case studies of disease – tuberculosis

TB is most commonly caused by the bacterium Mycobacterium tuberculosis which is spread by droplet infection.

Once the bacteria have been inhaled into the lungs they multiply slowly in the primary infection, often causing no obvious symptoms. If you have a healthy immune system, there will be a localised inflammatory response forming a mass tissue called a tubercule containing dead bacteria and macrophages.

The bacteria produce a thick waxy outer layer which protects them from the enzymes of the macrophages. The bacteria with effective coating will remain deep in the tubercules in the lungs, dormant or growing slowly for years until the person malnourished, weakened or their immune system does not work well. Then they produce active tuberculosis. In this way the most effective bacteria are selected and will be passed on. This helps to give them an edge in the evolutionary race between them and us.

- Typical symptoms of active TB
  - Fever
  - Night sweats
  - Loss of appetite
  - Loss of weight
  - Cough
  - Blood may be coughed up
  - Damage to lung tissue.

Eventually TB causes death, either because the individual cannot get enough oxygen from the air through their damaged lungs, or because their organs fail through lack of nutrition. And, since TB affects T cells, reducing the production of antibodies and weakening the immune system, sufferers often become very vulnerable to other, opportunistic infections.

Treatment

- Diagnosed by taking chest X-ray
- Treatment for tuberculosis is with antibiotics for many months.

Case studies of disease – HIV/AIDS

Acquired Immunodeficiency Syndrome (AIDS) is a relatively new disease, yet it is predicted that is could soon become the most prevalent cause of human death. AIDS is caused by the Human Immunodeficiency Virus (HIV).

The initial symptoms of an HIV infection are fevers, headaches, tiredness and swollen glands or there may be no symptoms. Three to 12 weeks after infection HIV antibodies appear in the blood and the patient is said to be HIV positive. All symptoms can then disappear for years but eventually patients suffer from weight loss, fatigue, diarrhoea, night sweats and infections. Finally there are several symptoms such as dementia, cancers and opportunistic infections such as TB and pneumonia.

How is HIV transmitted?

- through sexual contact
- through infected blood, by intravenous drug users sharing needles and by the use of infected blood products
- from a mother to her foetus in the early stages of pregnancy, during birth or through breastfeeding.

Evolutionary race between us and HIV

HIV targets T helper cells. It attaches the CD4 receptors on the T helper cells and infects them. HIV is a retrovirus and, once inside the T helper cell, it takes over the host DNA and replicates. When the new viruses leave the host T helper cell, it is destroyed. At the same time, host T killer cells recognise and destroy some of the heavily infected T helper cells. The result is a great reduction in T helper cells and a weakened immune system.

The usual approach to controlling disease is to produce an effective vaccine, but this is proving very difficult for HIV. The virus mutates rapidly so the antigens on the viral coat keep changing in the years after infection, making it harder for the immune system to recognise the virus and so target and destroy it. Natural selection also favours mutations that enable the virus to replicate particularly fast, allowing it to infect many cells as quickly as possible.